

Electric and Near-Field Acoustic Detection, A Monograph

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LONG-TERM GOALS

To complete and fully document my long-term ONR studies on the electric sense of sharks and rays, and on the low-frequency acoustic sense of fish in general.

OBJECTIVES

To publish a series of journal articles on the electromagnetic and low-frequency acoustic sensory systems of aquatic animals. The articles shall provide the mathematical-physics and sensory-biology background needed, present my theories and their experimental verification, and critically discuss the literature.

APPROACH

Weak electric and low-frequency acoustic fields have been studied to identify and mathematically define their biologically relevant features. Behavioral and neurophysiological experiments have been conducted under conditions ensuring that the results pertain to the normal functioning of the sensory systems.

The articles are meant for sensory biologists with an interest in physics and for physicists and engineers with an interest in sensory biology. They are intended to provide biologists with a better understanding of the physics involved, and physicists and engineers with a better feel for biological systems.

WORK COMPLETED

The articles concern my recent work on the electric sense of sharks and rays. I have greatly advanced my theory of electromagnetic orientation, its theoretical foundations, and its application to the animals. I have furthermore developed a guided-approach algorithm explaining how sharks and rays cue in on the source of an electric field. Moreover, I have discovered in the electroreceptors a novel new means of amplifying the weak electric field signals, while at the same time attenuating the sensor noise.

My work on inertial hearing in the acoustic near field has focused on the near-field physics of underwater sound, the sensory cues available in the acoustic near field, and the physiological properties of the inner-ear sense organs. It appears that the electrical approach algorithm can be applied to the detection of both the local and the vectorial derivative of the fluid velocity. The results of electrophysiological experiments conducted on fully submerged thornback rays support these theoretical inferences.

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RESULTS

The most significant result of my endeavor is the finding that the common bioelectric fields of prey and the acoustic near fields of moving underwater objects are governed by the same mathematical equation. Thus, the electric sense of sharks and rays, and the inertial sense organs of the inner ear of fish in general may make use of the same salient field features and apply essentially the same approach algorithm.

As for the inertial sense organs of the inner ear, I discovered an important new mode of excitation not yet considered. As acceleration detectors, the predator's inertial organs detect not only the temporal changes in the velocity field of the prey, but also the spatial changes in the velocity experienced over time as the predator moves through the field of the prey. However stealthy, no prey can escape detection.

Very recently, my studies on the detection of very weak electric fields has led to a surprise discovery. By placing the electrically excitable ion channels between the input and output of the receptor epithelium of the Lorenzinian ampullae, the electroreceptors of sharks and rays are capable of amplifying the electrical signal without amplifying the sensory noise, thus achieving very high signal-to-noise ratios.

IMPACT

The project is highly relevant to several Navy issues: (1) the electric and low-frequency acoustic detectability of submarines and other underwater vehicles, even when they are moving stealthily at a constant velocity, (2) the method to be utilized for guided missiles seeking sources of galvanic and fluid velocity fields, (3) fish bite and, in particular shark bite, at underwater cables, towed arrays, and other critical equipment and gear, (4) the environmental impact of naval oceanic activities.

TRANSITIONS

Because of my physics and engineering oriented approaches, all the results are expressed in a language rendering them directly available for naval and industrial implementation.

RELATED PROJECTS

The present project has not only yielded exciting new findings of its own, but by its nature also makes good use of all concurrent and earlier studies in my own laboratory and elsewhere.

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